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AFATL-TR-66-94

Explosives for Supersonic Munitions (U)

by

D. A. Pitt

Minnesota Mining and Manufacturing Company

OCTOBER 1966

AIR FORCE ARMAMENT LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
EGLIN AIR FORCE BASE, FLORIDA

EXPLOSIVES FOR SUPERSONIC MUNITIONS (U)

by

D. A. Pitt
MINNESOTA MINING AND MANUFACTURING COMPANY

(This page is Unclassified)

FOREWORD

This is the final report prepared on Project 670A, under Contract AF 08(635)-5224, "Explosives for Supersonic Munitions."

The work was administered under the direction of Mr. Carl Kyselka (ATWR), Air Force Armament Laboratory, Research and Technology Division, Air Force Systems Command, United States Air Force, Eglin Air Force Base, Florida, 32542.

This development program was conducted from 1 July 1965 to 31 December 1965 by the Minnesota Mining and Manufacturing Company, St. Paul, Minnesota, under the technical supervision of Dr. D. A. Pitt. The technical personnel assigned to the project were Mr. W. S. Anderson, Mr. G. D. Foss, and Dr. R. U. Schoenherr. Their work was supported and assisted by various 3M Company technical staff members.

This document, except the title, is classified CONFIDENTIAL in its entirety because of the nature of the material and military application of the data described.

This technical report has been prepared and marked in accordance with the DOD Industrial Security Manual by the contractor.

This technical report has been reviewed and is approved.

G. P. Brenner

GEORGE P. BRENNER, Col, USAF
Chief, Weapons Division

CONFIDENTIAL ABSTRACT

Selected materials have been evaluated for use in explosive formulations for use in munitions for supersonic aircraft missions, during which temperature excursions between -65°F. and 350°F. are expected. The explosive ingredients considered are 1-fluoro-2,4,6-trinitrobenzene (PF, picryl fluoride), 2,4,6-trinitrobenzotrifluoride (TNTF), in comparison with 2,4,6-trinitrotoluene (TNT), while the stipulated fuel ingredients are aluminum metal and aluminum hydride.

The preferred formulation is a mixture of 90 parts by weight of PF with 10 parts of aluminum. Factors favoring this system include superior total blast, as measured by the Trauzl test, and slightly more favorable physical properties. Stabilization of this system toward sedimentation of aluminum powder at temperatures above the melting point of the PF was attained by the addition of minor amounts of colloidal silica. Significant physical property data are reported on this system as well as other candidate systems.

Explosive formulations based on aluminum hydride give extensive gas evolution at elevated temperature.

The melting point of PF is exceeded during the mission of the supersonic aircraft. The PF formulation, therefore, cannot be considered as adequately meeting the goals of the Air Force. Armament limitations inherent to a system operating above its melting point suggest the evaluation of plastic-bonded systems containing higher melting explosives.

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SECTION I

INTRODUCTION

Supersonic military aircraft, because of the high speed attained during their missions, subject their explosive armaments to stagnation temperatures on the order of 350°F. Noise abatement and other considerations impose further requirements for low-temperature performance in that air temperatures in the subsonic portion of their flight path may be in the order of -65°F. Therefore, training requirements and operational readiness demand that the munitions carried must maintain their damage potential and their safe handling characteristics after repeated temperature cycling between these extremes. It is the objective of this study to define those explosive formulations which might meet these specific goals.

The requirements of this contract are to examine the performance of three specific high explosives with the selected fuel ingredients in the temperature range expected during a supersonic mission. The stipulated fuels are aluminum and aluminum hydride, and the explosives are TNT, TNTF (1-trifluoromethyl-2,4,6-trinitrobenzene) and PF (picryl fluoride, 1-fluoro-2,4,6-trinitrobenzene).

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SECTION II

TECHNICAL DISCUSSION

A. THEORETICAL STUDIES

In the execution of this contract, the computed blast properties, using the 3M Detonation Code, were used as a guide to optimizing formulation ingredients.

The 3M Detonation Code[1] is based on the virial equation of state. This routine has been used[2] to predict detonation pressure, temperature, volume, energy, and velocity in a wide variety of fluorinated materials and has been shown to be at least as accurate in these predictions as either the RUBY Code or the covolume relation of Cook.[3]

The 3M Code is to be preferred for a number of reasons. The form of the virial equation of state has fundamental meaning, and the virial coefficients themselves can be obtained from measurements independent of the detonation process. That this is a unique property of the virial equation alone has been noted by Cowan and Fickett,[4] among others. The importance of the virial equation is demonstrated by its extensive use to describe real gases at high pressures.[5]

The RUBY Code is based on the empirical Kistiakowsky-Wilson (K-W) equation[6] which is fitted from data on CHON explosives. Cowan and Fickett point out that for this reason RUBY is best suited to the prediction of detonation properties in conventional explosives. Mader[7] has used RUBY for the prediction of detonation behavior in several fluorinated systems, and found that additional

adjustments must be made in the covolumes of CF molecules to provide agreement with the experimental data. In contrast, modifications to the virial coefficients have not been required to fit data to fluorinated organic compounds.

Both the virial and K-W equations were derived initially to represent the behavior of one-component systems. The parameter of nonideality in the former case is the theoretically-grounded second virial coefficient, the value of which is determined from the constants of the intermolecular potential function. These are deduced, in the present case, from low-pressure equation of state measurements or from viscosity measurements. The parameter of nonideality in the K-W equation of state is the covolume, estimated from molecular geometries. In mixtures, both the virial coefficients and covolumes are taken as additive on a molar basis. Fickett[8] has recently pointed out the possible inadequacy of this assumption. The degree and direction of error introduced into the RUBY Code cannot be estimated. We have made rigorous calculations of the virial coefficients of mixtures using intermolecular potentials of the components. This has shown that the assumption of molar additivity introduces only minor errors.

A major advantage of using the virial equation of state is that simple, closed-form solutions for detonation parameters can be derived.[9] This permits rapid, inexpensive screening of a number of candidate systems, and also facilitates "tailor-making" of explosive formulations through correlation of the

computed parameters with various explosive test results which indicate performance.

The analysis given by the 3M Code indicates that detonation pressure is roughly proportional to $Q/(6\bar{n}-5)$, where $\bar{n}$ = average number of atoms per gaseous product molecule. The explosive stoichiometry, therefore, enters into detonation behavior through factors apart from the heat of formation. It has been observed[10] that Trauzl block results are roughly proportional to nT, or $\bar{n}Q$, where n = mols of gas per gram of explosive. As n rises, $\bar{n}$ falls, so the approximate equation for Trauzl performance may relate directly to detonation pressure. The deformation of the Trauzl block, which relates to the total blast, or available work potential[11] of the explosive, should correlate with the difference between the internal energy of the undetonated explosive and of the detonation products expanded isentropically from the C-J point to the yield point of lead. At the latter state, the temperature has fallen to 1000°K or less, and so a correlation was derived[12] relative to the products at 298°K. The Trauzl number is given by

$$k = a\,(Q_{tot} - fQ_{sol})$$

in which the constant f, as given by Cook,[11] is 0.5. By correlating the experimental Trauzl results with the calculated detonation product distributions, which give Q_{tot} and Q_{sol}, the coefficients a and f can be determined.

In the course of this contract, the 3M Detonation Code has been revised to provide a tighter tolerance on the detonation temperature. Using this revised program, the detonation parameters of several formulations were computed. These are presented in Appendix A. The experimental Trauzl block data from earlier work[12] was then correlated to the revised calculated results. A least-squares treatment was applied to the following equation:

$$k = a\,Q_{tot} - b\,Q_{sol} + c$$

in which k is the Trauzl number and

$$Q_{tot} = \sum_{\substack{\text{all}\\ \text{products}}} n_i \Delta H^{298}_{fi} - RT \sum_{\substack{\text{gaseous}\\ \text{products}}} n_j - \sum_{\substack{\text{ingre-}\\ \text{dients}}} n_k \Delta H^{298}_{f_k}$$

= energy of detonation

$$Q_{sol} = \sum_{\substack{\text{solid}\\ \text{products}}} n_i \Delta H^{298}_{fi} - RT \sum_{\substack{\text{gaseous}\\ \text{products}}} n_j - \sum_{\substack{\text{ingre-}\\ \text{dients}}} n_k \Delta H^{298}_{f_k}$$

= energy in condensed detonation products

This correlation resulted in the following values for the constants in the equation: a = 0.00014, b = 0.00018, c = 1.15. The equation was then used to calculate a theoretical Trauzl number for all of the computed explosive compositions. These calculations indicated an optimum Trauzl number of 1.23 for TNTF/Al explosive at 10% Al, and of 1.27 for PF/Al explosive at 5% Al. Experimental optima were found[12] at 10% loadings of

metal for both systems, and this loading was used for the experimental work reported below. Calculations for AlH_3 indicate a monotonic decrease in predicted Trauzl number and in detonation pressure with increasing AlH_3 content.

B. PREPARATION OF SAMPLES

Sample preparation involved weighing, blending, and melting of the organic explosive, followed by agitation of the melt. Only three areas required special attention. These are detailed below.

Stratification

It has previously been reported[12] that aluminized explosive formulations show a tendency to stratify or to precipitate the aluminum when the explosive is in the molten state. This is typically prevented in the cases of Torpex (41/41/18 TNT/RDX/Al) and Tritonal (80/20 TNT/Al) by simply avoiding prolonged exposure to high temperature. The special techniques of casting which are used to minimize the problem include 1) heating the formulation only slightly above the melting point of the H.E., 2) casting into cold vessels, 3) precasting sheets which are broken up, charged to an armament, after which the interstices are filled with additional molten material, and 4) by incremental casting.

None of the above is appropriate for a material which may be subjected, in a munition, to temperatures above its melting point. For this situation, the stratification rate must be altered. This could be done by 1) reducing particle size so as to approach a colloidal dispersion, 2) adjusting the apparent

density of the particle as through coating, 3) mechanically impeding stratification, as through introduction of a fragile open foam structure into which the cast material may flow, or 4) adjusting the apparent viscosity of the binder phase.

Preliminary examination would seem to indicate that, of the possible solutions, only the reduction of particle size could be accomplished without introduction of an inert loading. However, in practice an inert loading must be introduced even here. Aluminized explosives are not loaded with pure aluminum, but rather with particles of aluminum coated with a layer of inert aluminum oxide. Geometrical considerations will make apparent the rapid increase of this inert loading relative to the active aluminum as the size of individual particles is decreased. Direct observations indicated that reduction of particle size had failed to prevent stratification up to the point at which the inert aluminum oxide had increased to about 1.5% by weight of the total explosive or about 15% by weight relative to the weight of aluminum. This also represented the limit of commercially available spherical or atomized aluminum. Flake aluminum suffered even more severely from increase in aluminum oxide loading as may be seen by the geometry. Here there was a greater, though still inadequate, retardation of settling.

Aluminum oxide loading can be avoided through use of ultra-fine aluminum particles produced and handled in an inert atmosphere. It was established that such particles are not now commercially available. Since they are pyrophoric in air, there is a good

probability that they would react with the binder, at least to the extent of producing a protective inert film on the individual particle.

Adjustment of the apparent density of the particle appears impractical on consideration that the inert or void loading which would be required to bring the density of aluminum, about 2.7, to that of the explosive, about 1.6.

Adjustment of the apparent viscosity of the explosive through addition of small amounts of "Cab-o-Sil" was studied. At a loading of 2% by weight, stratification was effectively prevented while maintaining a castable formulation. This loading is not necessarily an optimum, since this would be influenced by available casting equipment as well as by settling rate and energetic considerations.

Thermal Cycling

Temperature cycling was proposed to be carried out through use of a semi-automatic apparatus, shown in Figure 1. The extremes of temperature and the characteristics of the heat transfer liquid (2-ethylhexyl acetate) resulted in short operational life of the solenoid valves, and manual operation was thus required. It is recommended that any additional testing work utilize a positive-action valving arrangement, e.g., air-operated ball valves equipped with "Teflon" packing.

Temperature cycling was standardized at ten cycles with a cycle period of approximately 45 minutes. Desired temperature

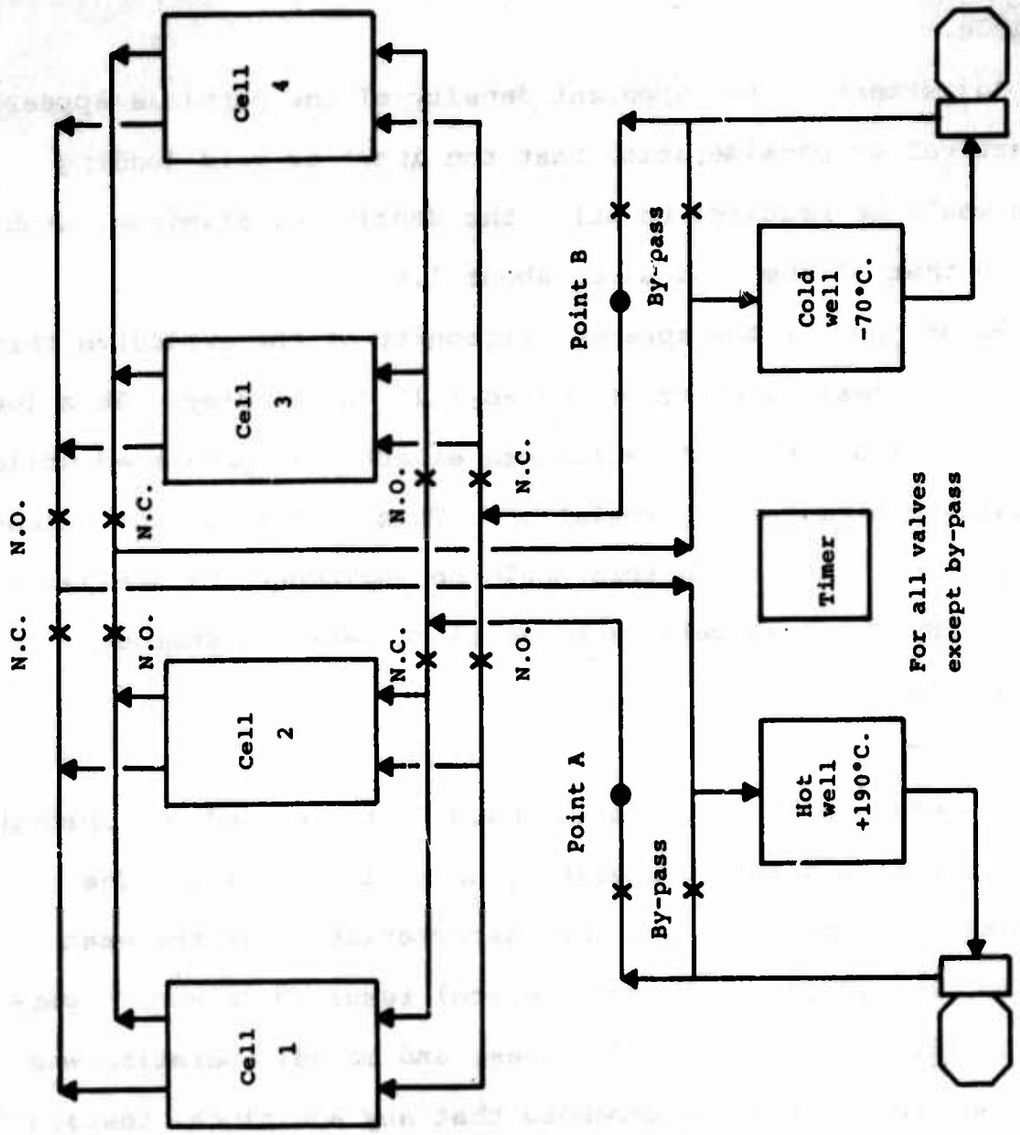

Figure 1. Temperature Cycling Equipment

extremes were -54°C. and +175°C. The high temperature objective was met. However, the equipment was limited to a lower extreme of -45°C. The characteristics of the temperature cycle are illustrated in Figure 2.

Handling of Aluminum Hydride

Aluminum hydride exists in crystal forms of varying stability. Of these, the most stable form currently available is that designated as type 1451. A preliminary supply of 25 grams of this material was obtained from the Dow Chemical Company, Freeport, Texas. The 3M Company provided a glass bulb fitted with "Teflon" stopcocks and vacuum fittings to allow transfer without exposure to the atmosphere with its attendant moisture. All glassware was blackened to protect the sample from exposure to light since it is reported to be sensitive to radiation. The sample was received under a blanket of dry inert gas.

All glassware for Taliani and other tests was baked dry under vacuum before receiving samples of aluminum hydride. Positive closure was assured by heat sealing the glass under vacuum after transfer of the sample. Exposure to grease was avoided through use of the above mentioned "Teflon" stopcocks. The initial 25 gram sample was sufficient to provide data which clearly defined the limitations of this material.

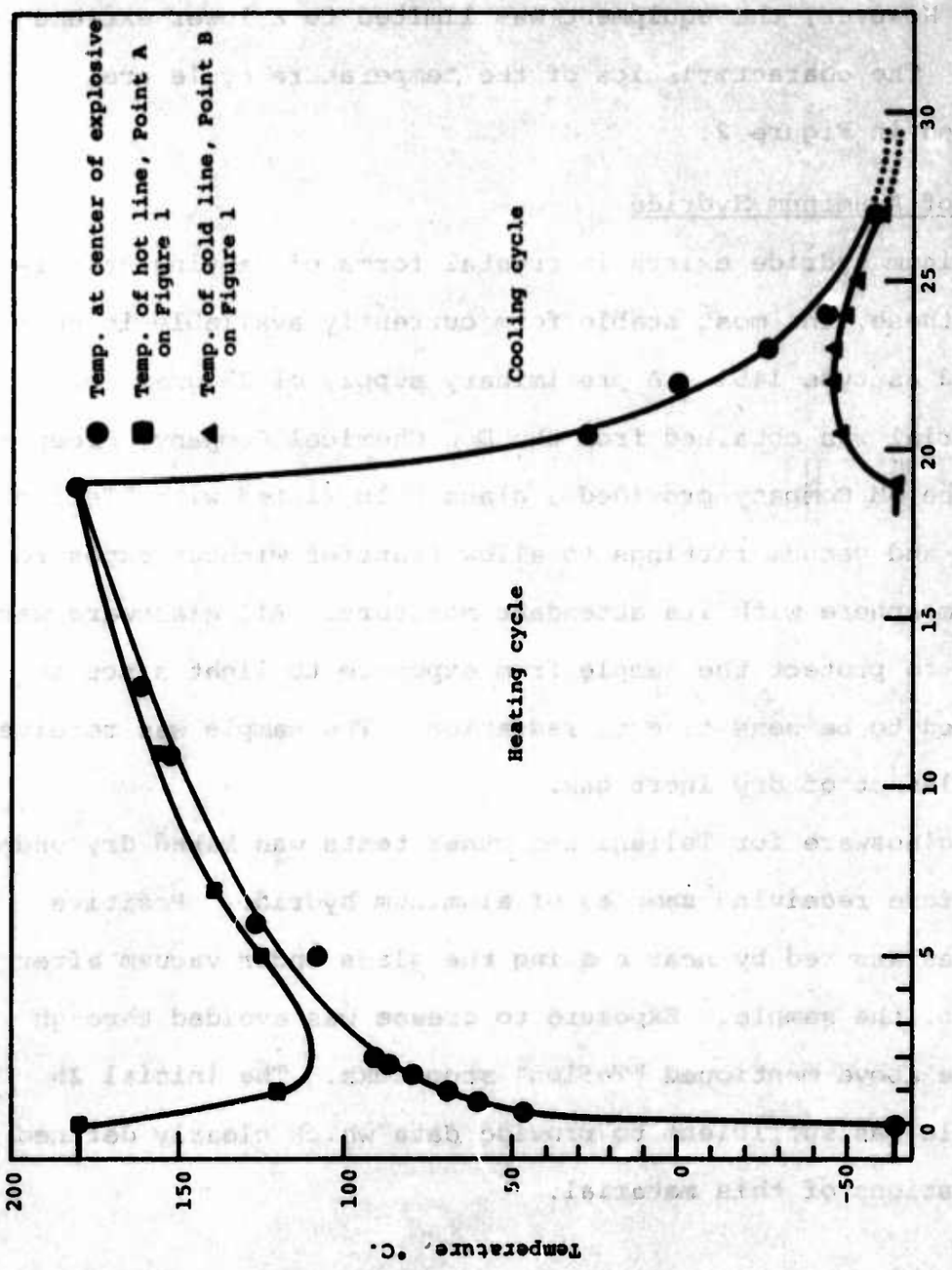

Figure 2. Temperature Cycling Curve

C. EVALUATION OF SAMPLES

Evaluations under this contract pertained to the explosives TNT, TNTF, and PF in their pure state and at optimum loadings of both aluminum and aluminum hydride. Ability to withstand high temperature exposure (175°C. for a minimum of one hour) and temperature cycling are prime requirements.

Thermal Stability

All candidate materials were subjected to Taliani testing at 100°C. These data are presented in Tables B-1 to B-7 and are summarized in Table C-1. The results may be summarized as indicating that the pure explosives and the aluminumized formulations are well within allowable limits for conventional use. Thermal stability, as measured by dwell at 175°C., is reported below with the results of the temperature cycling studies.

Aluminum hydride, by contrast, is outside of allowable limits. The data of Table B-3 and Figure B-1 are in agreement with data of the Dow Chemical Company on the same subject.[13] The thermal decomposition of aluminum hydride appears, from Figure B-2, to be considerably increased by the presence of the explosive. Although the latter was treated under vacuum, some moisture could have been introduced in this way. A limited amount of 150°C. Taliani work in pure aluminum hydride is also presented in Table B-3 and Figure B-3 of Appendix B. By agreement with the sponsor, after consideration of these results, work with aluminum hydride was terminated.

Total Blast

The spherical Trauzl test[14] using a 6.4 inch diameter lead ball[15] was the basis for determining total blast[12] effect. This nomenclature is used because explosive "power" implies a rate of energy release, whereas the subject test is more correctly a measure of the total effect integrated over time. Trauzl numbers are summarized in Table C-2.

Detonation Velocity

Detonation velocity was determined by the Bureau of Mines procedure.[16] Data was obtained with the arrangement shown in Figures 3 and 4. For measurements at ambient temperature, 23°C., the H.E. was contained in a steel pipe of 0.5 in. inside diameter and 4 in. length. At elevated temperatures, 175°C., the environment cell was used as illustrated. Ambient temperature work proceeded smoothly and results are in fair agreement with the literature as given in Table C-3. These data represent the results of three or four velocity measurements.

Several difficulties were encountered in making determinations of detonation velocity at elevated temperature. Of these, the most serious was the marginal temperature stability of the available insulating varnishes protecting the coiled portion of the detector probe. This was especially serious in the case of the aluminized formulations, and in some cases, only one usable velocity result was obtained. The equipment, shown diagrammatically in Figure 4, includes a hydraulic activator to bring the initiator to the sample just prior to firing.

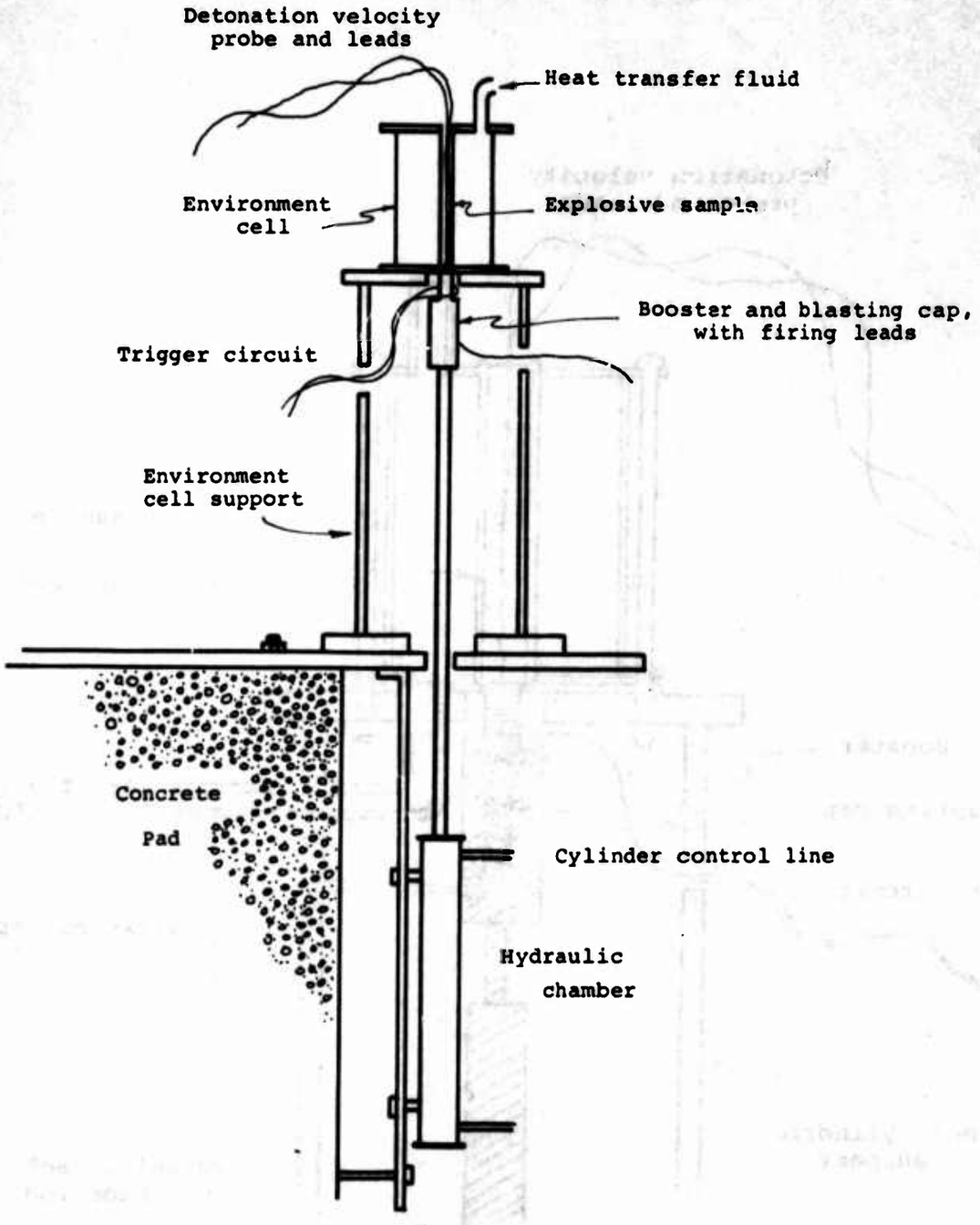

Figure 3. Detonation Velocity Apparatus

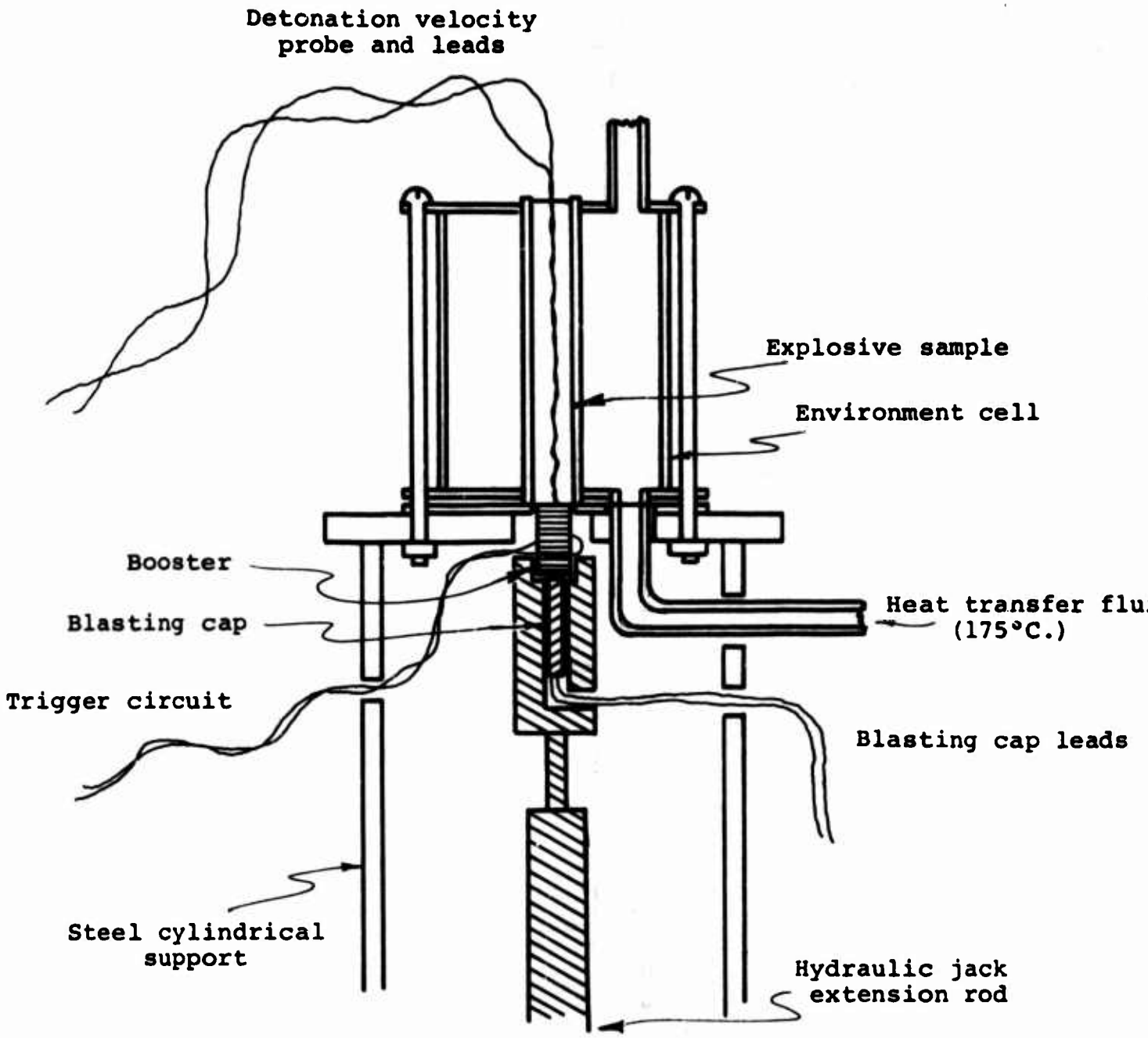

Figure 4. Detail of High Temperature Detonation Velocity Apparatus

Impact Sensitivity

In no case was the maximum impact (200 kg-cm) available from the machine, Figure 5, sufficient to initiate an explosion of the three explosives of interest. For comparison, the h_{50} value of PETN was found to be 14.2 cm with the 2 kg drop weight.

Density

Determination of density utilized a remote Westphal balance, as shown in Figure 6. An aluminum weight was first calibrated against water and then immersed in the molten cast explosive. The procedures followed ASTM method B-311-58. Values were determined at 150° and 175°C., which previously had been established as design criteria. Determinations were made only for the pure explosives since this data would then be adequate to calculate the apparent densities of various metal loadings. The results are presented in Table C-4.

Coefficient of Thermal Expansion

This determination was made by ASTM Method D-696-44. Figure 7 illustrates the essential features of one method. Measurements were made in the temperature interval between 25°C. and 75°C. The coefficients were calculated and are presented in Table C-4 for the pure explosives. Coefficients for aluminized formulations may be calculated from the precent loading, using literature values for aluminum.

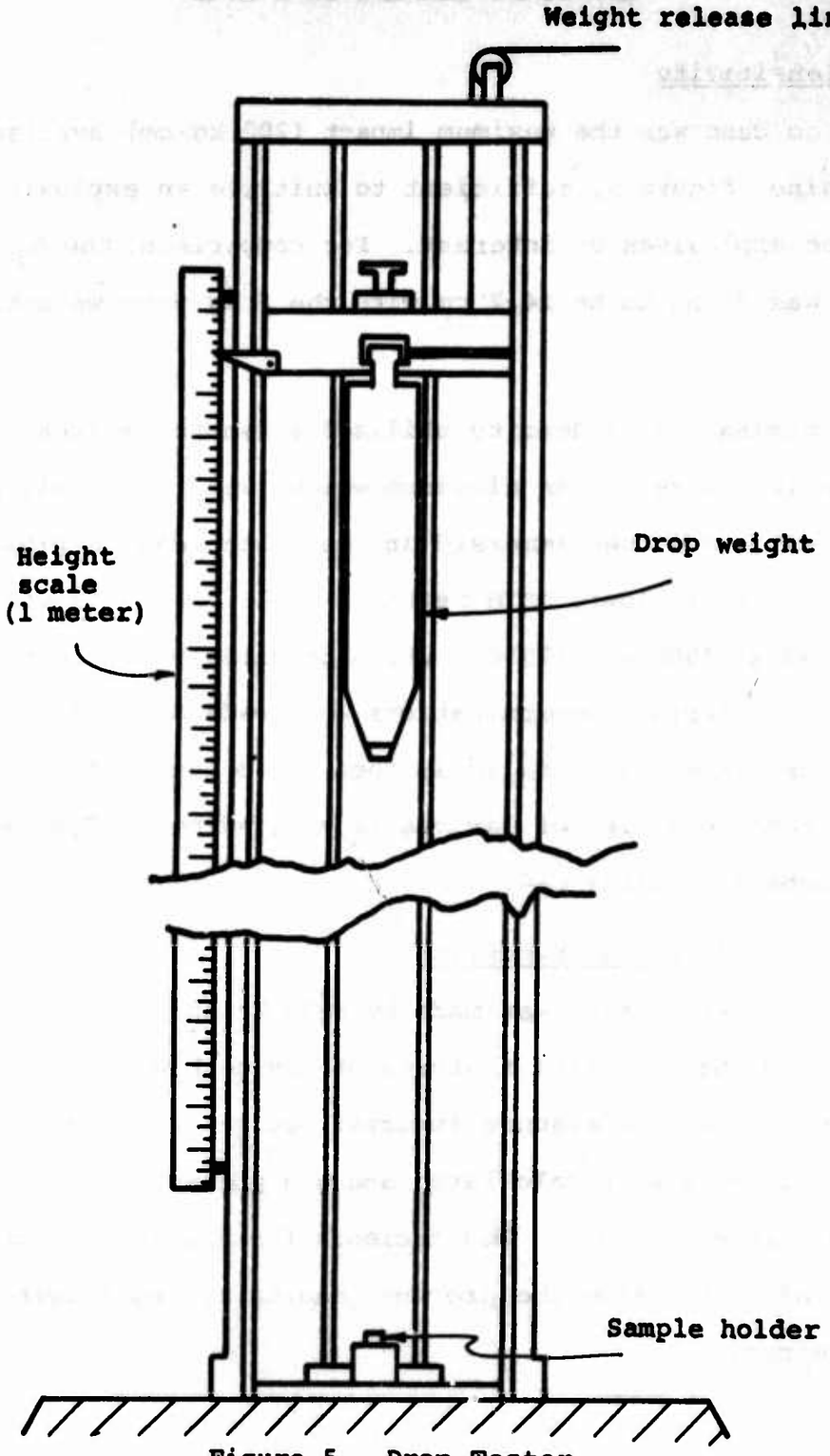

Figure 5. Drop Tester

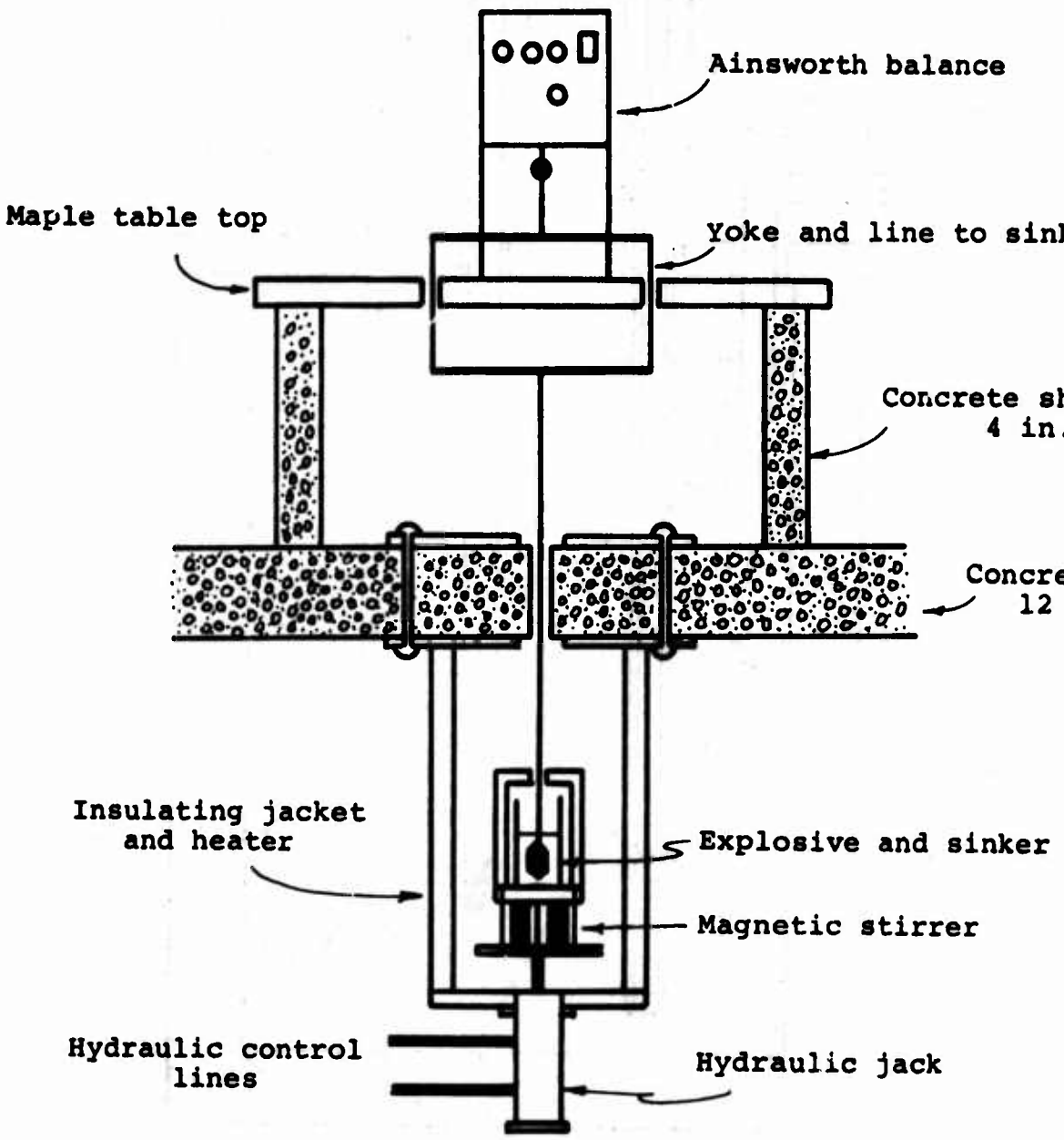

Figure 6. High Temperature Density Apparatus

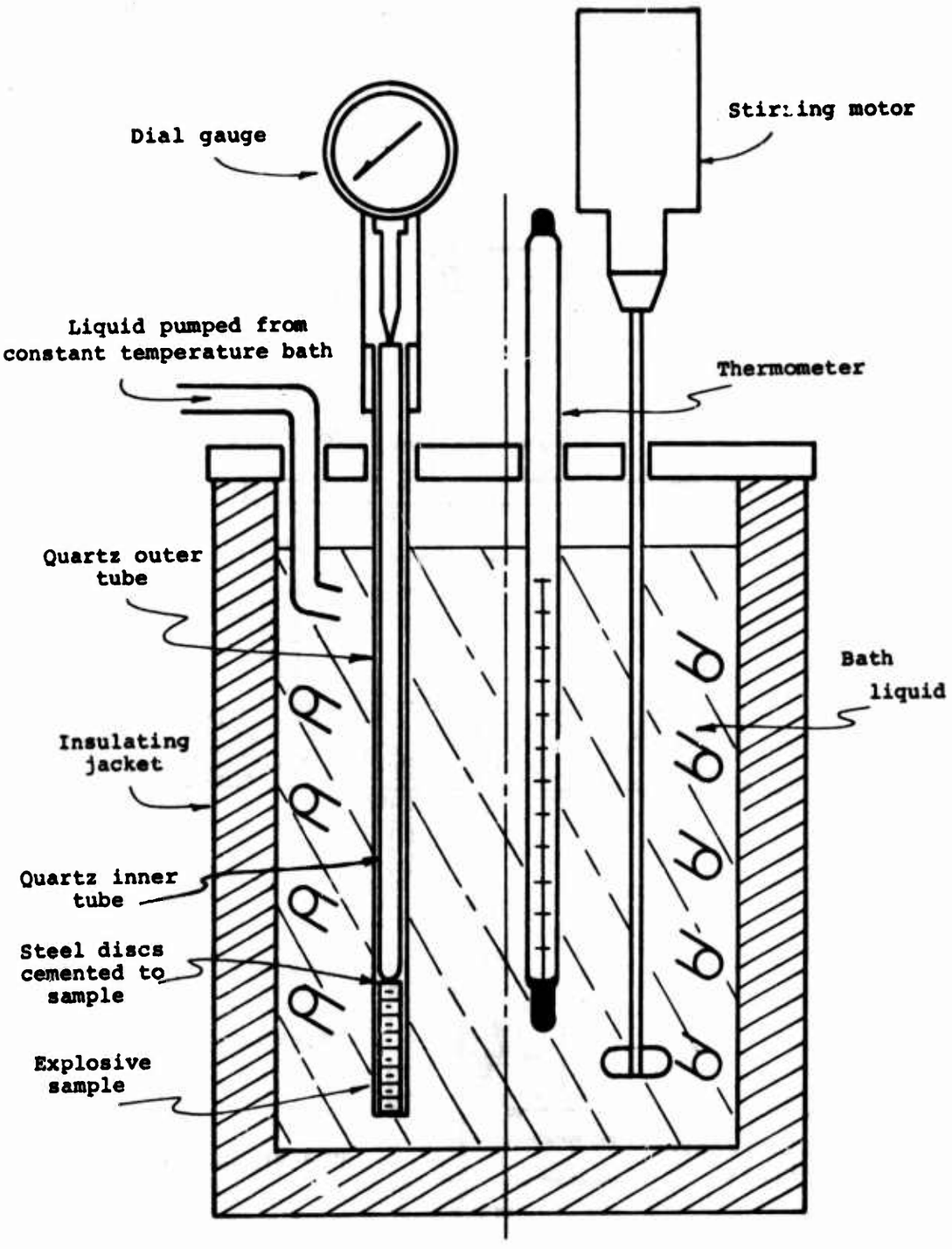

Figure 7. Linear Expansion Apparatus

Vacuum Stability

Taliani data were collected as a first measure of thermal stability and are discussed above. Results are presented in Appendix B and are summarized in Table C-1. The pure explosives and the aluminized formulations easily meet the goal requirements of Classification I of the Navy System, i.e., not more than 2 cc. of gas at STP per gram per 48-hour period at 100°C. No significant change is noted when temperature cycled materials are considered. Aluminum hydride gave copious gas evolution, and cannot be considered suitable for explosive formulations.

Heat of Combustion

The heats of combustion of TNT, TNTF, and PF are important measures of the thermochemical performance of these explosives. The heats of combustion of TNT and TNTF have been measured earlier,[12] and are reported for comparison in Table C-6. As a part of this present contract the heat of combustion of PF has been determined.

The experimental method for determining heats of combustion of compounds containing CHONF is well documented,[20,21] and these established procedures were followed throughout this work.

The PF samples were mixed with a predetermined amount of mineral oil and placed in a platinum crucible. The mineral oil is adequate to assure the formation of HF from fluorine atoms in the explosive. The crucible containing the sample and oil is then placed on supports inside the platinum-lined calorimeter bomb. A 10 ml. volume of water is placed on the bottom of the bomb, a

cotton fuse is fixed in place, the bomb is sealed and is pressurized to 30 atmospheres with oxygen. The fully-loaded bomb is then placed within a carefully regulated constant temperature jacket. After an initial rating period, the sample is ignited electrically and the temperature rise is recorded. About one minute after the sample is ignited, the bomb is caused to rotate for a period of five minutes to ensure complete dissolution of the acidic gases into the bomb water.

After the thermal part of the experiment is complete, the products of combustion are analyzed. These analytical data are then used to calculate the standard heat of combustion, which is reported in the table below.

Table 1. The Heat of Combustion Data for PF

Expt No.	Sample Wt. g.	Wt. of Auxiliary Oil, g.	Temperature Rise, °C.	Std. Heat of Combustion, cal/g.
346	.40000	.47545	1.75909	-2772.1
347	.39985	.47250	1.74997	-2775.0
348	.39965	.47076	1.74520	-2780.5
			Average	-2776

The calorimeter energy equivalent was determined by calibrating in the standard manner with benzoic acid. The energy equivalent was found to be 3604.79 calories per degree.

The heats of combustion of aluminized formulations were calculated from the experimental standard energy of combustion of the high explosive, with the heat of formation of Al_2O_3 reported by Rossini, et al.[22] These values are also shown in Table C-5.

Heats of Explosion

Heats of explosion were determined for PF and the formulations of 10 weight percent Al powder 1-131 with the explosives TNT, TNTF, and PF. No account has been taken of the Al_2O_3 content of the aluminum, which would greatly affect the heat yield of experiments with other aluminum powders. The samples were prepared by casting them in pellets weighing about five grams. These samples were then placed in a crucible supported inside a standard Illium combustion bomb. The bomb was purged and then pressurized to 20 atmospheres with argon gas.

There was a great deal of difficulty in causing the samples to ignite. Double-base propellant was unsatisfactory as an initiator as very large amounts were needed. Heavy wire fuses would ignite the samples fairly reliably. This electrical energy input was measured in separate experiments. Since conditions were quite different from normal combustion runs, each run was calibrated with electrical energy. We were thus able to keep the experimental errors to a minimum. The data show considerable scatter, however, primarily due to a variability in explosion product distribution. In addition to the normally expected products of the explosion, such as water, oxides of carbon, nitrogen and oxides of nitrogen. a large amount of sooty material was formed in the bomb. The latter absorbed varying amounts of gaseous and liquifiable explosion products, and its analysis was not undertaken.

Melting Points

Melting point determinations were made before and after temperature cycling. These are presented for comparison in Appendix C-6.

Castability

Castability of all formulations was subjectively judged to be "good." Addition of "Cab-o-Sil" quickly reduces the pourability of the formulations, but improves the strength characteristics of the casting. Castings of TNTF show poorest structural strength and greatest tendency toward voids, due to the needle-shaped crystals which develop on solidification.

Temperature Cycling

Additional samples were prepared for exposure to thermal cycling to determine whether such exposure results in a change of properties. The temperature cycling program included dwell at 175°C. for a period in excess of one hour during at least one cycle. All samples survived this treatment. Comparison of the exposed explosives with uncycled samples was made through melting point determinations, Trauzl testing, impact testing, and Taliani testing. As may be seen from Appendix C, no significant change of properties was detected. These results would reflect any increased decomposition that might be due to impurities accumulated during dwell at the high temperature.

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

This investigation was conducted to determine whether the specified systems were capable of reaching certain performance goals. All testing was carried out on cast samples in order to simulate field use as closely as possible. For missions properly defined by these goals, the system PF/Al, at 90/10 weight ratio, is the preferred formulation of those systems studied. This result is based upon less severe temperature requirements than those of earlier work, which favored the TNTF/Al system. Factors favoring the PF/Al system over aluminized TNT and TNTF include the superior total blast, as measured by the Trauzl test, and slightly more favorable physical properties, particularly melting point and crystal structure of the casting. However, the melting point is exceeded during the mission of the munition in which this explosive would be used. The PF/Al formulation, therefore, cannot be considered as adequately meeting the goals of the Air Force. Armament limitations inherent to a system operating above its melting point suggest the evaluation of alternate explosives of higher melting point which are capable of being cast in a plastic matrix.

For interim use, the optimization of the "Cab-o-Sil" loading must be accomplished. Consideration must also be given to melt casting methods and equipment.

The high temperature detonation velocity measurements are presented with the reservation that further development of this test configuration will be required before standardization of

the data can be attained. Since the test temperature is above the melting point, a liquid phase detonation velocity is measured.

Explosive formulations based on aluminum hydride give extensive gas evolution at 100°C. The present form of this material is not suitable for use in explosives.

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APPENDIX A

COMPUTED DETONATION PARAMETERS

Table A-1. Aluminized TNT Explosives

Composition:						
TNT	100	90	85	80	75	70
Al	--	10	15	20	25	30
Detonation Parameters:						
T_{Det}, °K.	4089	4378	4640	4904	5384	564[illegible]
D_{Det}, M/S	7922	8350	8108	7723	6218	5440
P_{Det}, kbars	181	199	189	173	114	87
Q_{tot}	1183	1258	1392	1540	1874	2030
Q_{Gas}	907	806	770	718	635	530
Q_{Sol}	276	452	622	821	1239	1500
Spec.Vol.,cc/g.	.617	.593	.580	.568	.556	.543
ΔH_f,kcal/100 g.	-784	-706	-666	-627	-588	-549
Moles gas/gram	2.51	2.28	2.00	1.71	1.20	1.00
Product Distribution: moles/100 grams						
$Al_2O_3(s)$	--	1.85	.278	.370	.463	.556
C (s)	1.566	1.156	1.167	1.192	1.625	1.628
HCN	.03	.138	.158	.177	.064	.072
CHO	.02	.080	.084	.080	.030	.017
CH_4	.107	.116	.101	.088	.067	.064
CO	.05	.442	.393	.325	.029	.016
CO_2	1.125	.537	.380	.234	.213	.050
C_2H_2	.001	.023	.03[illegible]	.042	.005	.007
C_2H_4	.08	.120	.127	.131	.132	.143
H_2	.002	.021	.020	.019	.001	.002
H_2O	.316	.224	.173	.125	.103	.048
NH_3	.24	.076	.068	.061	.171	.157
N_2	.523	.486	.447	.407	.375	.344

Table A-2. Aluminized TNTF Explosives

TNTF	100	97.5	95	92.5	90	86	83	80
Al	--	2.5	5	7.5	10	14	17	20
Spec.Vol	.549	.545	.540	.536	.532	.524	.519	
ΔH_f	-554	-540	-526	-512	-499	-476	-460	
T°K	4242	4595	4911	5192	5313	5318	5465	5783
D	8029	8343	8594	8777	9867	9068	8710	8285
P	201	214	223	227	279	238	220	200
Q_{Tot}	993	1138	1286	1436	1330	1452	1545	1673
Q_{gas}	797	820	824	808	719	690	641	547
Q_{sol}	196	318	462	728	611	761	904	1126
Moles gas/ 100 grams Expl.	2.067	1.950	1.833	1.714	2.138	1.675	1.513	1.49
$AlF_3(s)$		.092	.185	.278	.264	.273	.263	.234
$AlF_3(g)$						.011	.012	.0003
$Al_2O_3(l)$					.053	.116	.176	.253
C(S)	1.09	1.11	1.14	1.17	.87	.924	.979	1.13
HCN	.022	.028	.033	.039	.106	.126	.132	.139
CHO	.015	.021	.027	.034	.021	.086	.083	.018
CO	.037	.041	.044	.048	.909	.424	.385	.580
CO_2	.742	.78	.818	.86	.329	.448	.353	.113
HF	.017	.012	.008	.004	.164	.021	.019	.145
H_2O	.117	.111	.104	.099	.153	.062	.052	.107
NO	.0008	.001	.002	.003	.005	.005	.003	.005
N_2	.48	.465	.450	.437	.419	.347	.364	.347
COF_2	.48	.35	.211	.07	.0008	.012	.010	.0003
NH_3	.08	.075	.070	.066	.005	.014	.013	.007

Table A-3. Aluminized PF Explosives

PF	100	97.5	95	92.5	90
Al	-	2.5	5	7.5	10
Spec. Vol	.555	.551	.546	.542	.537
V_o cc/g	-195	-190	-185	-180	-175
T_{Det} °K	5025	5205	5369	5488	5675
D_{Det} MPS	8973	9377	9334	9169	8834
P_{Det} kbars	248	264	262	253	234
Q_{Total}	1262	1344	1431	1500	1605
Q_{Gas}	999	977	945	921	815
Q_{Solids}	263	366	477	577	791
Moles gas/ 100 g. Expl.	2.23	2.18	2.06	1.93	1.86
Product Distribution Moles/100 g.					
AlF_3(s)		.09	.115	.112	.114
Al_2O_3(l)			.035	.083	.128
C (s)	1.18	1.10	1.13	1.16	1.50
CO	.005	.05	.056	.054	.11
CO_2	1.14	1.12	1.05	.953	.712
HF	.0005	.004	.002	.002	.04
H_2O	.094	.127	.119	.111	.333
N_2	.55	.560	.544	.528	.56

Table A-3. Aluminized PF Explosives (Continued)

PF Al	87.5 12.5	85 15	80 20	75 25
Spec. Vol	.532	.528	.519	.509
V_o cc/g	-170	-166	-156	-146
T_{Det} °K	5713	5554	5798	6037
D_{Det} MPS	8741	9297	7843	
P_{Det} kbars	231	258	227	184
Q_{Total}	1636	1482	1642	1817
Q_{Gas}	839	773	687	580
Q_{Solids}	797	709	955	1237
Moles gas/ 100 g. Expl.	1.68	1.85	1.57	1.27
Product Distribution Moles/100 g.				
AlF_3 (s)	.106	.095	.080	.076
Al_2O_3 (L)	.178	.228	.323	.417
C (s)	1.23	.87	.973	1.08
CO	.049	.448	.373	.279
CO_2	.75	.442	.288	.149
HF	.002	.02	.019	.010
H_2O	.09	.06	.05	.032
N_2	.495	.452	.416	.380

Table A-4. TNT/AlH_3 Explosives

TNT	100	90	80	75	70	65
AlH_3	--	10	20	25	30	35
Spec.Vol.	.617	.620	.624	.628	.631	.639
ΔH_f	-784	-798	-811	-818	-825	-832
Detonation Parameters						
T °K	4089	4362	4508	4588	4740	4639
D MPS	7922	6547	4894	4285	4503	7298
P kbars	181	128	77	61	64	147.9
Q_{Tot}	1183	1466	1762	1907	2064	1923
Q_{Gas}	907	779	782	795	849	1095
Q_{Sol}	276	687	980	1112	1215	828
Moles gas/ 100 grams Expl.	2.51	2.42	1.97	1.75	1.60	1.74
Product Distribution Moles/100 g. Expl.						
Al_2O_3(l)	--	1.67	.333	.417		.571
C (s)	1.57	2.29	2.27	2.18		.110
CO	.05	.283	.057	.017		.002
CO_2	1.125	.126	.003	--		--
CH_4	.107	--	.003	.018		.43
C_2H_4	.09	--	--	--		.540
H_2O	.316	1.320	1.039	.709		--
NH_3	.24	.077	.487	.803		.150
N_2	.523	.516	.211	.036		.263

Table A-5. TNT/AlH_3 Explosives

TNTF AlH_3	100 --	88.3 11.7	85 15	80 20	75 25	70 30	65 35
Spec.Vol	.549	.565	.569	.576	.583	.589	.596
ΔH_f	-554	-501	-485	-461	-438	-415	-392
Detonation Parameters							
T °K	4242	4989	5006	5016	5046	5121	5046
D MPS	8029	7647	6892	5693	4565	4308	4981
P kbars	201	173	143	103	69	60	74
Q_{Tot}	993	1526	1622	1771	1952	2109	2133
Q_{Gas}	797	757	730	704	707	744	812
Q_{Sol}	196	769	892	1067	1145	1365	1321
Moles gas/ 100 grams	2.43	2.10	2.00	1.83	1.53	1.34	1.32
Product Distribution							
AlF_3 (S)		.24	.215	.18	.208	.207	.21
Al_2O_3 (L)		.07	.14	.24	.31	.40	.42
C (S)	1.09	1.53	1.66	1.70	1.78	1.6	1.21
CO	.04	.31	.24	.09	.01	--	--
CO_2	.74	.29	.15	.01	--	--	--
HF	.017	.227	.262	.30	.176	.123	.06
H_2O	.117	.71	.815	.83	.64	.3	.09
NH_3		.018	.03	.14	.47	.72	.68
N_2	.48	.43	.4	.30	.11	--	--

Table A-6. PF/AlH_3 Explosives

PF	100	90	80	70
AlH_3	--	10	20	30
Spec.Vol	.556	.568	.580	.562
ΔH_f	-195	-250	-232	-259
Detonation Parameters:				
T °K	5158	5060	5093	5076
D MPS	9414	8035	5914	4523
P kbars	266	195	112	69.5
Q_{Tot}	1251	1488	1781	2030
Q_{Gas}	942	830	755	783
Q_{Sol}	309	658	1026	1247
Moles gas/100 g.Expl.	2.55	2.145	1.99	1.60
Product Distribution Moles/100g. Expl.				
AlF_3 (S)	--	.069	.029	.018
Al_2O_3 (L)	--	.132	.318	.491
C (S)	1.18	1.582	1.882	1.63
CO	.005	.277	.085	.011
CO_2	1.14	.438	.027	--
HF	.0005	.182	.257	.248
H_2O	.099	.736	.955	.331
N_2	.55	.552	.405	.022

APPENDIX B

TALIANI TEST DATA

Table B-1. Taliani Test Results

100°C. Bath Temperature

	Identification	Weight, g.	Tube Volume, ml.
Samples:	No. 1 Eastman TNT	1.00	17.1
	No. 2 Eastman TNT	1.01	17.3
	No. 3 Military TNT	1.01	17.3
	No. 4 Military TNT	1.01	17.5
	No. 5 TNTF	1.00	17.2
	No. 6 TNTF	0.96	15.9

Time	Volume of Gas Evolved (Cm^3 of gas at STP/gm of sample)					
Hours	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
0	0.0	0.0	0.0	0.0	0.0	0.0
1/6	0.1344	0.1335	0.0	0.0	0.0	0.0153
1/2	0.1344	0.1500	0.0	0.0	0.0	0.0153
1	0.1344	0.1670	0.0	0.0	0.0	0.0153
2	0.1344	0.1670	0.0	0.0	0.0	0.0153
5.5	0.1344	0.1670	0.0	0.0	0.0	0.0153
16	0.1680	0.1835	0.0167	0.0168	0.0167	0.0306
17.5	0.2019	0.2170	0.0334	0.0336	0.0334	0.0459
18.5	0.2019	0.2170	0.0501	0.0504	0.0501	0.0612
19.5	0.2019	0.2170	0.0501	0.0504	0.0501	0.0612
20.5	0.2019	0.2170	0.0501	0.0504	0.0501	0.0612
22.5	0.2019	0.2170	0.0501	0.0504	0.0501	0.0612
24	0.2019	0.2170	0.0501	0.0504	0.0501	0.0612
40	0.2019	0.2170	0.0501	0.0504	0.0501	0.0612
42	0.2019	0.2170	0.0501	0.0504	0.0501	0.0612
48	0.2019	0.2170	0.0501	0.0504	0.0501	0.0612

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Table B-2. Taliani Test Results

100°C. Bath Temperature

	Identification	Weight, g.	Tube Volume, ml.
Samples:	No. 1 PF	1.01	25
	No. 2 PF	1.00	25.5
	No. 3 Al 1-131	1.00	24.8
	No. 4 Al 1-131	1.02	25.5
	No. 5 Al 40-XD	1.02	24.8
	No. 6 Al 40-XD	1.03	24.8

Time	Volume of Gas Evolved (Cm^3 of gas at STP/gm of sample)					
Hours	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
0	0.0	0.0	0.0	0.0	0.0	0.0
1/6	0.0241	0.0735	0.1224	0.1201	0.5370	0.6240
1/2	0.0482	0.0979	0.1470	0.1439	0.7010	0.7160
1	0.0482	0.0979	0.1713	0.1678	0.8870	0.8775
1-1/2	0.0482	0.0979	0.1960	0.1919	0.6540	0.6460
16-1/2	0.0482	0.0979	0.2690	0.2620	0.6540	0.6460
17-1/2	0.0482	0.0979	0.2690	0.2620	0.6540	0.6460
19-1/2	0.0482	0.0979	0.2690	0.2620	0.6771	0.6700
21-1/2	0.0482	0.0979	0.2690	0.2620	0.7010	0.6930
22-1/2	0.0482	0.0979	0.2939	0.2861	0.7230	0.7160
23-1/2	0.0482	0.0979	0.2939	0.2861	0.7460	0.7390
24-1/2	0.0482	0.0979	0.2939	0.2861	0.7460	0.7390
40	0.0482	0.0979	0.2939	0.2861	0.7940	0.7850
41-1/2	0.0482	0.0979	0.3185	0.3090	0.7940	0.7850
44-1/2	0.0482	0.0979	0.3185	0.3339	0.8170	0.7850
48	0.0482	0.0979	0.3430	0.3339	0.8170	0.8090

Table B-3. Taliani Test Results

100°C. Bath Temperature - Samples 1-4
150°C. Bath Temperature - Samples 5,6

	Identification	Weight, g.	Tube Volume, ml.
Samples:	No. 1 AlH_3	1.680	23.17
	No. 2 AlH_3	1.690	23.56
	No. 3 AlH_3	0.107	22.37
	No. 4 AlH_3	0.458	22.53
	No. 5 AlH_3	0.381	22.05
	No. 6 AlH_3	0.335	22.65

Time	Volume of gas evolved (Cm^3 of gas at STP/g. of sample)					
Hours	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
0	0	0	0	0	0	0
1/12					0.3685	0.3175
1/6	0.0795	0.0804	0.1999	0.0708	13.760	8.070
1/4					33.90	34.60
1/3	0.1265	0.1274	0.3998	0.0708		
1/2	0.1265	0.1274	0.4999	0.1653		
2/3	0.1265	0.1274				
1	0.2190	0.2280	0.6999	0.2360		
2-1/4	1.825	1.849	3.599	1.419		
3-1/4	2.770	2.848	7.990	3.400		
4-1/4	7.990	8.950	31.20	15.13		
4-1/2	10.13	10.33				
5-1/4			61.80	30.85		
5-1/3			71.00	34.81		
6			107.7			

Table B-4. Taliani Test Results

100°C. Bath Temperature

	Identification		Weight, g.	Tube Volume, ml.
Samples:	No. 1 90/10	TNT/Al	1.01	17.4
	No. 2 90/10	TNT/Al	1.01	17.2
	No. 3 90/10	TNT/Al	1.00	17.3
	No. 4 90/10	TNTF/Al	1.01	17.4
	No. 5 90/10	PF/Al	1.01	17.2
	No. 6 90/10	PF/Al	1.00	17.1

Time	Volume of gas evolved (Cm^3 of gas at STP/gm of sample)					
Hours	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
0	0.0	0.0	0.0	0.0	0.0	0.0
1/6	0.0167	0.0164	0.0	0.0166	0.0656	0.0490
1/2	0.0167	0.0164	0.0	0.0335	0.0656	0.0490
15	0.0167	0.0164	0.0166	0.0335	0.0656	0.0490
18	0.0167	0.0164	0.0166	0.0335	0.0656	0.0490
21	0.0335	0.0328	0.0333	0.0501	0.0656	0.0490
22	0.0335	0.0328	0.0333	0.0500	0.0650	0.0490
39	0.0502	0.0492	0.0333	0.0500	0.0650	0.0490
42	0.0502	0.0492	0.0499	0.0500	0.0650	0.0490
48	0.0502	0.0492	0.0499	0.0500	0.0650	0.0490

Table B-5. Taliani Test Results

100°C. Bath Temperature

	Identification	Weight, g.	Tube Volume, ml.
Samples:	No. 1 TNT 0.200 gm AlH_3	0.2376	26.6
	No. 2 TNT 0.200 gm AlH_3	0.1562	26.9
	No. 3 TNTF 0.200 gm AlH_3	0.3496	26.5
	No. 4 TNTF 0.200 gm AlH_3	0.0770	26.1

Time	Volume of gas evolved (Cm^3 of gas at STP gm of sample)			
Hours	Sample 1	Sample 2	Sample 3	Sample 4
0	0.0	0.0	0.0	0.0
1 3	0.1461	0.2540	0.1627	0.3175
2 3	0.2340	0.2905	0.232	0.3175
1	0.2340	0.2905	0.232	0.3175
1-1 2	1.3440	0.6530	1.023	0.5440
2.0	10.59	2.325	8.60	1.905
3.0	18.07	8.78	16.12	7.070
3.5	29.35	14.38	27.55	12.15
3.75	--	--	34.40	--
4.0	44.00	22.70	--	18.89
4.5	--	32.20	--	36.25
5.0	--	42.10	--	36.25

Table B-6. Taliani Test Results

100°C. Bath Temperature

	Identification	Weight, g.	Tube Volume, ml.
Samples:	No. 1 TNT (cycled)	1.00	21.3
	No. 2 TNT (cycled)	1.00	21.3
	No. 3 TNTF (cycled)	1.00	21.3
	No. 4 TNTF (cycled)	1.00	21.3
	No. 5 PF (cycled)	1.00	21.3
	No. 6 PF (cycled)	1.00	21.3

Time	Volume of gas evolved (Cm^3 of gas at STP/gm of sample)					
Hours	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
1/2	0.0710	0.0304	0	0.0507	0.0304	0.0304
16-1/4	0.1055	0.0446	0.0244	0.0851	0.0446	0.0649
23	0.0913	0.0507	0.0304	0.071	0.0913	0.071
136	0.1602	0.0792	0.0792	0.0994	0.0994	0.0792

Table B-7. Taliani Test Results

100°C. Bath Temperature

Identification	Weight, g.	Tube Volume, ml.
No. 1 90 10 PF Al (cycled)	1.00	21.3
No. 2 90 10 PF Al (cycled)	1.00	21.3
No. 3 90 10 TNTF Al (cycled)	1.00	21.3
No. 4 90 10 TNTF Al (cycled)	1.00	21.3

Time	Volume of gas evolved (Cm^3 of gas at STP/gm of sample)			
Hours	Sample 1	Sample 2	Sample 3	Sample 4
5/6	0.0609	0.0405	0.0405	0.0810
2	0.0994	0.0994	0.0994	0.1199
15	0.0568	0.0568	0.0568	0.0974
21	0.0365	0.0365	0.0365	0.0974
40	0.0851	0.1055	0.0851	0.1462
48	0.1036	0.1238	0.1036	0.1643

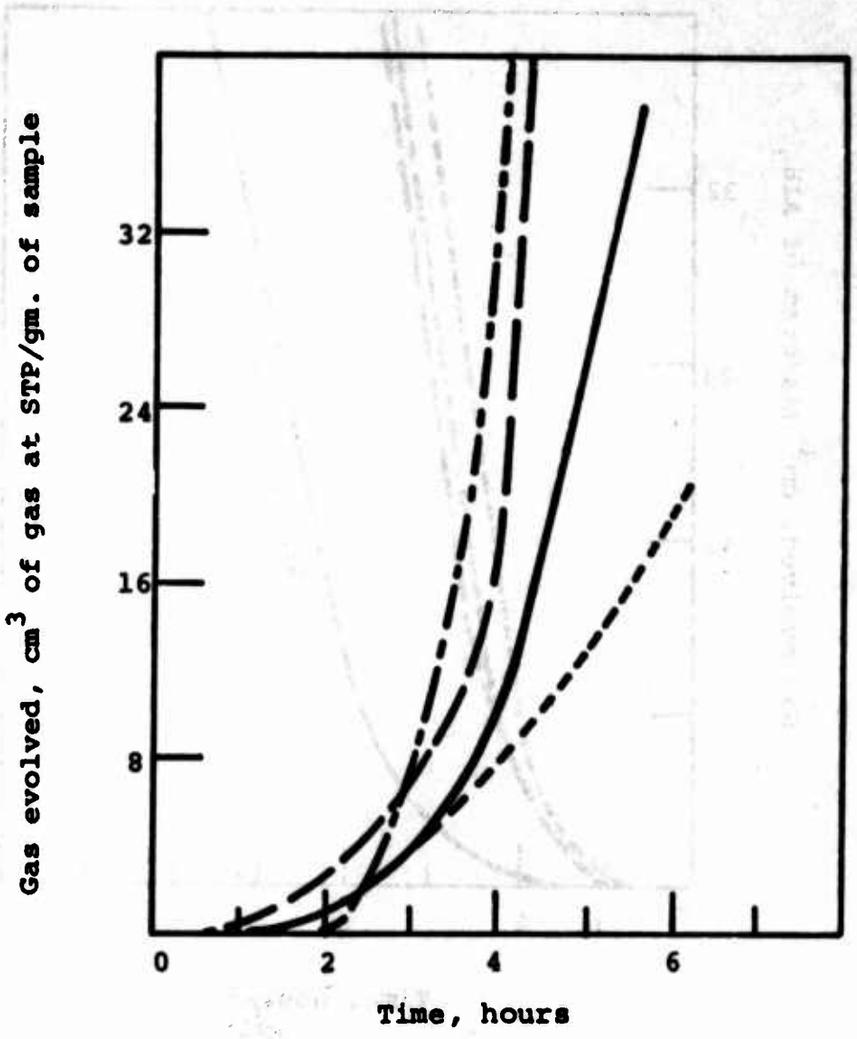
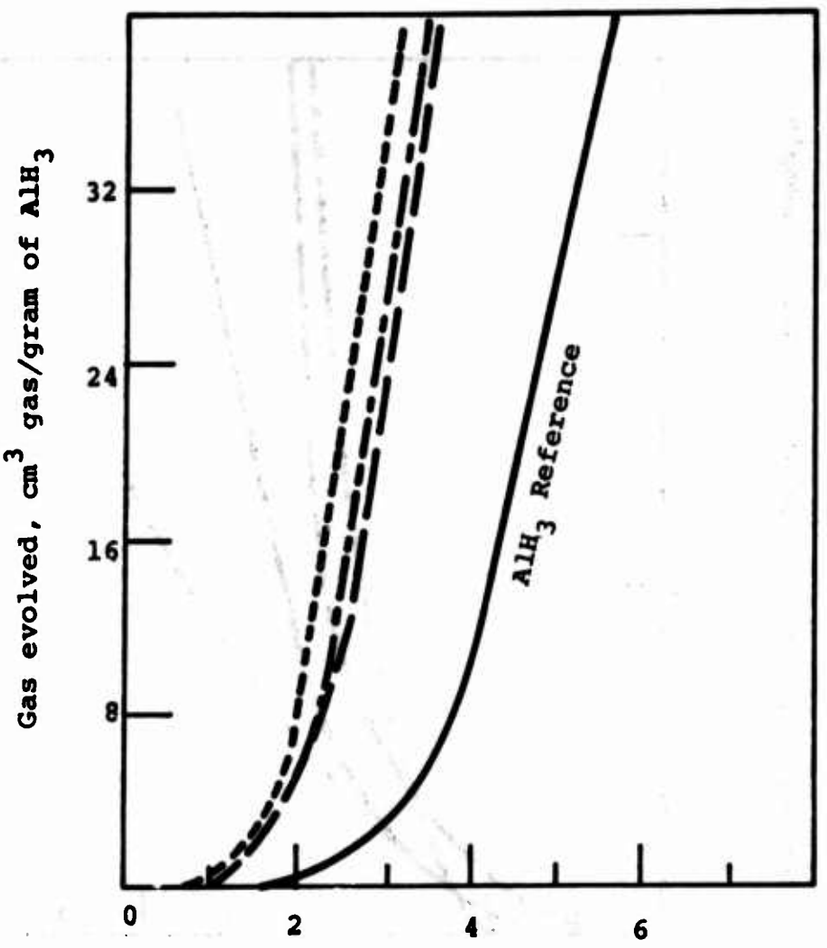


Figure B-1. Taliani Results, AlH_3 at 100°C.



0.2370 grams AlH_3, 0.200 grams TNT
0.1560 grams AlH_3, 0.200 grams TNT
0.3496 grams AlH_3, 0.200 grams TNTF
0.0770 grams AlH_3, 0.200 grams TNTF
0.458 grams AlH_3

Figure B-2. Taliani Results, AlH_3 with Explosive Binders at 100°C., referred to weight of AlH_3 only.

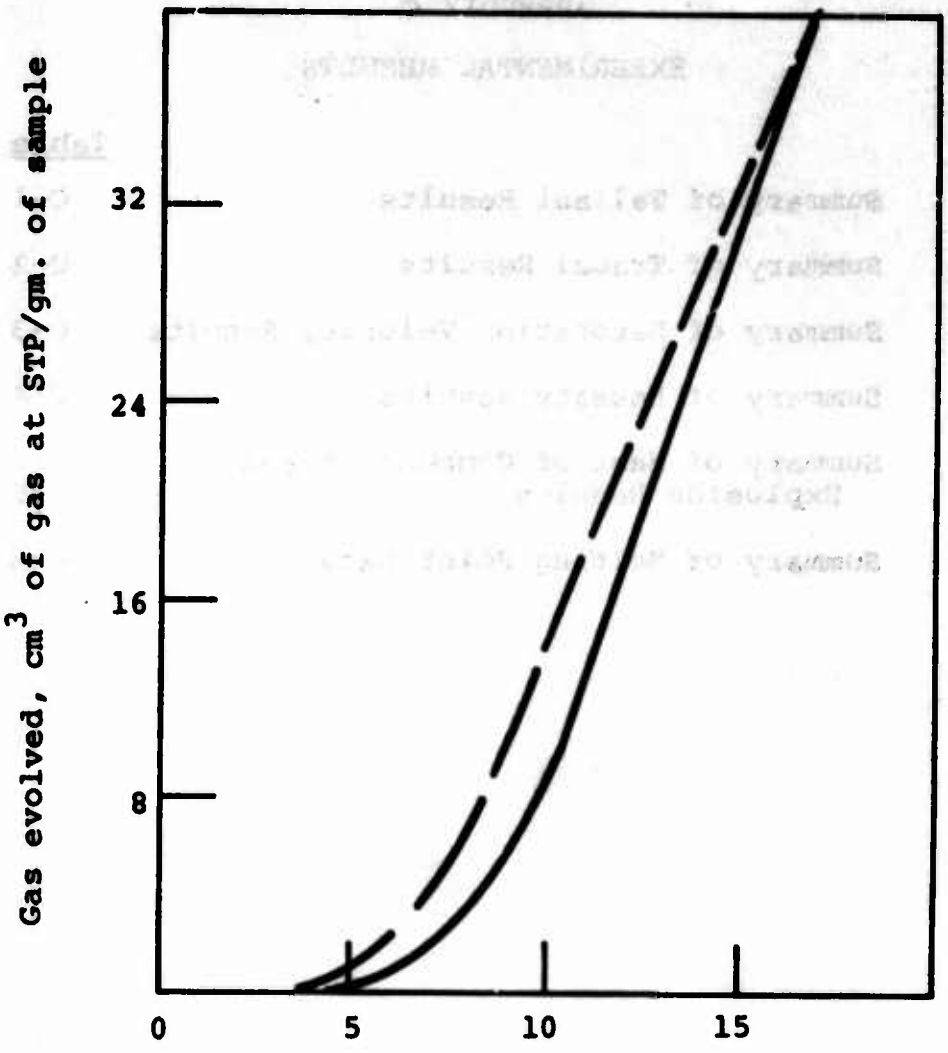


Figure B-3. Taliani Results, AlH_3 at 150°C.

APPENDIX C

EXPERIMENTAL RESULTS

Table C-1. Summary of Taliani Test Results

System	Gas Evolution cc. of gas at STP/gram of sample after 48 hours at 100°C.	
	Uncycled Samples	Cycled Samples
TNT[a]	0.05	0.09[b]
TNTF	0.06	0.06[b]
PF	0.07	0.08[b]
Al	0.34	--
AlH_3	8-44[c]	--
90/10 TNT/Al	0.05	--
90/10 TNTF/Al	0.05	0.13
90/10 PF/Al	0.06	0.11

a. Military grade

b. Estimated by interpolation

c. After 4 hours at 100°C.

Table C-2. Summary of Trauzl Results

System	Trauzl Numbers		
	Uncycled Samples		Cycled Samples
	Experimental	Literature Reference 12	Experimental[a]
TNT	1.00	1.00	1.07
TNTF	1.00	1.05	1.05
PF	1.20	1.22	1.18
90/10 TNT/Al	1.24	1.23	--
90/10 TNTF/Al	1.20	1.23	1.17
90/10 PF/Al	1.39	1.31	1.30

a. Relative to uncycled TNT as unity. The weight of "Cab-O-Sil" (2% of the weight charged) was subtracted from the measured weight in calculating the Trauzl number of the cycled samples.

Table C-3. Summary of Detonation Velocity Measurements at 23°C.

System	Detonation Velocity, mm./μ sec.					
	Experiments	Literature				
		Ref.12	Ref.15	Ref.17	Ref.18	Ref.19
TNT	6.89	7.18	6.835	--	6.825	6.9
TNTF	6.50	6.97	7.17	7.185	6.919	--
PF	7.36	--	7.515	7.656	7.182	--
90/10 TNT/Al	7.10	6.85	--	--	--	6.7[a]
90/10 TNTF/Al	6.97	6.90	--	--	--	--
90/10 PF/Al	6.36	--	--	7.86[b]	--	--

a. 20% aluminum by weight

b. 10% aluminum by weight

Table C-4. Summary of Density Measurements

System	Density		Coefficient of Linear Expansion
	150°C	175°C	
TNT	--	--	7.70×10^{-5}
TNTF	1.62	1.59	2.59×10^{-5}
PF	1.60	1.59	5.26×10^{-5}

Table C-5. Summary of Heat of Combustion and Heat of Explosion Results

System	Heat of Combustion cal/g	Heat of Explosion cal/g
TNT	3538[a]	648[b]
TNTF	2492	759
PF	2776	842
90/10 TNT/Al	3562	690
90/10 TNTF/Al	2578	1080
90/10 PF/Al	2836	1090

a. Lit: 3589.5 cal/g., Ref. 19;
3620 cal/g., Ref. 23;

b. Lit: 1080 cal/g., Ref. 23

Table C-6. Summary of Melting Point Data

System	Uncycled Samples		Cycled Samples
	Experimental	Literature	
TNT	79	80[a]	78
TNTF	91	84[b]	89
PF	127	132[b]	127

a. Ref. 19

b. Ref. 15

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13. ABSTRACT

(U) Two candidate explosives and their formulations with fuel ingredients have been compared to TNT for performance in the temperature range from -65°F. to the stagnation temperature expected on supersonic aircraft. Physical property data on preferred formulations are presented, with recommendations on their utility in the proposed application.

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